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ABSTRACT

This study investigates the strategies people use to acquire knowledge from maps. Among the questions examined were (1) what distinguishes poor learners from good learners, and (2) how do the learning strategies of map-using experts differ from those of nonexpert learners? Eight subjects participated in the study. Five were undergraduate students at the University of California at Los Angeles and three were experts with military or scientific expertise in map reading. All subjects were given two maps of an imaginary town and country. They were allowed six trials of two minutes each in which to learn the information in the maps well enough to draw them from memory and answer questions about their contents. During the six trials they were required to think aloud about how they were going about learning the maps. Analysis of the subjects' verbal reports and performance on a test of map content indicated that four types of learning processes were used: attention, encoding, evaluation, and control. The use of processes for encoding spatial information (storing it in long-term memory and relating it to other information already learned) was most predictive of learning performance. Good learners differed from poor learners in their ability to evaluate their learning progress and to focus their attention on unlearned information. (Author/AV)

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Individual Differences in Knowledge Acquisition from Maps

Perry W. Thorndyke, Cathleen Stasz

A Report prepared for

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PREFACE

This report is the first in a series of investigations of the process of map learning. The work reported here was performed between November 1977 and May 1978 and was supported by the office of the Director of Personnel and Training Research Programs, Psychological Sciences Division, Office of Naval Research. Additional research in this area is continuing and will be documented in subsequent reports.

The report analyzes in detail the strategies that people use to learn maps and identifies those strategies that are diagnostic in predicting successful learning performance. The findings should interest researchers and instructors in map use and spatial cognition.

SUMMARY

This study investigates the strategies people use to acquire knowledge from maps. On each of a series of learning trials, three expert and five novice map users studied a map and provided verbal protocols of their study behavior. Analysis of the learning protocols suggested four categories of processes that were invoked during learning: attention, encoding, evaluation, and control. Large individual differences in both performance and strategy usage were observed in this task. Analyses of the performance and strategy data revealed that the use of certain strategies in each category, particularly those used for encoding spatial information, was most predictive of learning performance. In addition, good learners differed from poor learners in their ability to evaluate their learning progress and to focus their attention on unlearned information. An analysis of the performance of map-using experts suggested that success in learning depended on strategies and not on familiarity with the task domain or materials. The implications of these results for training expertise in map learning are discussed.

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I. INTRODUCTION

Information about the names and locations of places and objects in the world is available from a variety of sources. Knowledge of a particular area typically derives from such sources as maps, verbal directions or descriptions, photographs, movies, and personal experience in the region. Maps are a particularly good source, because they provide a concise symbolism for displaying vast amounts of information. They display both explicit information about object names, shapes, and locations and implicit information about the spatial relationships and distances among the objects.

People often memorize part or all of a map in order to perform various tasks, including selecting a route or navigating between points, identifying land features and objects in the terrain, and estimating distances between locations. Undoubtedly, many processes employed in learning also support other map-using functions such as locating objects and orienting oneself in an unfamiliar terrain. This report examines the processes people use to acquire knowledge from maps and the relationships between those processes and successful learning performance. We attempt to provide some insight into the knowledge-acquisition process by identifying the learning strategies and control processes people use when studying a map. We shall consider several related questions:

- Are there large individual differences in map learning performance?
- Do people use numerous and diverse study strategies?
- What distinguishes good learners from poor learners?
- How do the learning strategies of map-using experts differ from those of nonexpert learners?

To answer these questions, we require a research methodology that allows a detailed analysis of similarities and differences in

subjects' information processing behavior during learning. Traditionally, psychological research in individual differences has used a psychometric methodology. The psychometric approach emphasizes the search for abilities or traits that underlie differences among individuals in performance and that predict correlations in performance on various tasks. Recently, however, some psychologists have begun to study individual differences as differences in processes, rather than in abilities (Sternberg, 1977; Hunt, 1978; Snow, 1978). Using what may be called a cognitive approach, these researchers have attempted to understand the componential processes that combine to produce complex task performance and to analyze variations in these processes.

The present study adopts such a cognitive approach to investigate some of the high-level componential processes in learning and to examine their relationship to overall performance. While we cannot hope to enumerate all the componential processes involved in learning, we can identify some of the differences between good and poor learners in observable processing strategies.

Although some prior research in environmental psychology has investigated issues related to spatial knowledge acquisition, little attention has been given to map learning per se. Rather, most of this reseach has focused on people's geographic perceptions of their environment. These perceptions are derived from experiences in the world and are reflected in attitudes and preferences, as well as in spatial knowledge of the environment. Several studies have investigated correlations between subjects' social, economic, and personal attributes and the environmental knowledge they exhibit when drawing maps of their locale (Lynch, 1960; Beck and Wood, 1976; Downs and Stea, 1973, 1977). Other studies have investigated the development of spatial knowledge derived solely from navigational experience (Siegel and White, 1975; Hardwick, McIntyre, and Pick, 1976; Siegel, Kirasic, and Kail, 1978). These studies provide interesting data on the factors influencing a person's knowledge of the world, but they do not investigate maps as a source of knowledge.

One study of map learning (Shimron, 1975) has suggested that subjects appear to learn local details on a map before integrating them into a global organization. However, none of these studies of learning and perception considers in depth the processes by which map users acquire knowledge.

In the following sections we examine in detail the problem of learning a map. First, we characterize the map learning problem and contrast it with other, traditional learning tasks. Second, we outline the theoretical framework adopted for interpretation of learning strategies. We then present data from a learning experiment that demonstrate the relationship between strategies and performance, and we discuss the performance of poor learners in terms of deficiencies in processing strategies. Finally, we summarize our findings and contrast them with those from other studies of individual differences.

II. THE MAP LEARNING PROBLEM

For our purposes, we have defined a "map" to be a symbolic two- or three-dimensional representation of an area large enough for a person to navigate, such as a building, city, country, or continent. Spatial representations of such entities as DNA chains, molecules, desk tops, or rat mazes are not included in our investigation.

We assume that map learning, like other learning tasks, is a constructive process that produces in long-term memory a representation of the stimulus. In map learning, this knowledge representation encodes many types of information, including concepts, their linguistic and spatial properties (e.g., names, shapes, and location), and relationships among the concepts (e.g., distances and relative directions). Because learning in this situation is an active, intentional process, we view the task as similar to a problem-solving task. The goal state corresponds to complete learning of the map, and the problem-solving operators are high-level learning strategies the subject applies to produce a memory representation of the map. These strategies are typically rich and varied and presumably vary across individuals, materials, and tasks.

While many high-level processes invoked during map learning undoubtedly occur in other experimental learning situations, map learning tasks differ in two important ways. First, a map is more complex than typical experimental learning materials. To succeed, the subject must learn and integrate both verbal and spatial information. He must apprehend and memorize a set of named objects and places, their shapes and physical extent, and details of their absolute and relative positions on the map. For example, consider the representation of a highway on a city map. A red line symbolizing a highway has a verbal label associated with it that designates its name or highway number. The highway also has a two-dimensional spatial representation that provides information about shape, distance, capacity, and direction. In addition, other spatial information is

portrayed by the relationships between the highway and other elements on the map, such as the intersection of two highways or the location of a building adjacent to the highway. The map-learning task requires acquiring and integrating all of this verbal and spatial information. In contrast, typical learning studies have used stimuli composed of either purely spatial or visual information (e.g., photographs, faces, shapes) or purely verbal information (e.g., lists of words, sentences, texts).

The second unique characteristic of the map learning task is that all information to be learned is presented simultaneously rather than sequentially. In experimental learning paradigms, the information to be learned usually comprises several items presented sequentially to the subject over time. When learning a map, however, the subject is presented with the entire configuration of information to be learned at once. In this case, the subject, rather than the experimenter, decides how to attend to subsets of the available information selectively, how much time to spend studying portions of the information, and how many times to study different portions of the information. These task characteristics make the map learning situation similar to natural learning situations.

As a consequence of these differences between our task and other experimental tasks, the strategies subjects use to learn a map may differ markedly from those used in learning situations in which the stimuli are entirely verbal or spatial and the presentation of information is under an experimenter's control. This task, then, might be expected to produce differences in performance and processing strategies among individuals that would not emerge on simpler learning tasks.

In order to explicate the role that the processing strategies play in learning, we must make some assumptions about the organization of human information processing. Following many other theories of human cognition (e.g., Newell and Simon, 1972; Anderson and Bower, 1973; Hunt, 1978), we assume that the construction of a memory description depends upon an existing body of semantic knowledge and a collection of processes. The processes are used to create and encode new knowledge and integrate it with previously acquired knowledge.

Both knowledge and processes reside in unlimited-capacity long-term memory and can be activated and used in a limited-capacity working memory. Working memory refers to that portion of long-term memory in which active processing is currently taking place and activated concepts are held.

We assume that many componential processes operate in memory, at varying degrees of abstraction, to manipulate and transform knowledge. Each process may be thought of as a complex production system or set of condition-action rules (Newell and Simon, 1972; Hunt, 1978). A process can be activated when some attributes of the information in the working memory satisfy the conditions for its applicability. When activated, the process takes as input a set of information in memory and executes its particular actions, resulting in some transformation of that information. This transformation may consist of new memory structures, concepts, or relationships.

The processes include some that are automatic and require little or no processing resources and some under conscious control that must compete for limited-capacity resources (Posner and Snyder, 1975). At the lowest levels, there are mechanistic processes (Hunt, 1978) that are either automatic (e.g., decoding a linguistic string and recognizing the meaning of a familiar word) or conscious (e.g., manipulating focus of attention on sensory channels or manipulating information in active memory). The conscious processes may be selected, controlled, and monitored by the learner, depending upon his knowledge of and skill at using various strategies. At higher levels, there are knowledge-based processes--additional conscious processes whose use depends upon comprehension of the meaning of the information being manipulated and related world knowledge. For example, a subject might choose to learn a list of words by creating semantic categories into which subsets of the words fit.

While a growing body of literature has examined individual differences in the low-level processes, particularly those involved in linguistic processing (Hunt, Frost, and Lunneborg, 1973; Hunt, Lunneborg, and Lewis, 1975; Hunt, 1978; Jackson and McClelland, 1978),

little research has examined high-level learning strategies. A few studies of immediate recall have considered the relationship between performance and the use of strategies such as imagery (Paivio, 1971; Rohwer, 1973) or rehearsal and chunking (Belmont and Butterfield, 1971; Estes, 1974; Lyon, 1977; Cohen and Sandberg, 1977; Voss, 1978). In addition, studies of problem solving have investigated various solution strategies (Newell and Simon, 1972; Mayer and Greeno, 1972; Mayer, 1975; Johnson, 1978). However, research on learning strategies in other task domains has largely ignored individual differences.

Our attention in this study focuses on differences in high-level processes between individuals and the relationship between strategies and performance. Given our characterizations of the learning problem and the processing system, we now propose several hypotheses regarding subjects' task performance.

First, it seems plausible that differences in learning performance can be traced to differences in high-level processing strategies. Each subject presumably draws strategies from a pool during acquisition. If certain strategies are particularly useful for learning, subjects who use these strategies should perform better than subjects who don't. This condition might arise in two ways: Good learners might exhibit a greater number of strategies than poor learners, including those strategies that were most advantageous for learning. Alternatively, poor learners might use as many strategies as good learners, but those strategies might not be effective.

On the other hand, performance differences may be independent of particular high-level strategies. For example, performance may depend solely on low-level, mechanistic processes or on the speed of execution of basic processes. If this is the case, learning rate should be unrelated to patterns of particular strategy use.

Since a map contains both spatial and verbal information, subjects might use different encoding strategies for learning the two types of information. Prior research has suggested that spatial and verbal information have different memory representations (Brooks, 1973; Shepard, 1975; Baddeley, Grant, Wight, and Thomson, 1975;

Kosslyn, 1975, 1976; Kosslyn and Pomerantz, 1977). Furthermore, operations on the mental representations of spatial information closely resemble perceptual processes that operate on external, visual stimuli (Shepard and Metzler, 1971; Cooper and Shepard, 1973; Cooper, 1975, 1976; Cooper and Podgorny, 1976; Kosslyn, Ball, and Reiser, 1978; Shepard, 1978; Shepard and Podgorny, 1978). These studies suggest that a person learning a map might process and store the spatial information (shapes, sizes, locations) differently from the verbal information. For example, appropriate techniques for chunking and elaborating verbal information should be different from those for spatial information. A person studying a map would be expected to switch among a variety of learning strategies, depending on the type of information on which he or she is focusing.

Finally, we are interested in contrasting the map learning strategies used by experts with those used by novices. We would expect the performance of experts to be superior to that of novices for one of two reasons: (1) Experts may develop specialized processing strategies that are particularly useful for using maps, or (2) experts might perform the same operations as novices, but they might perform those operations faster and more efficiently because of their familiarity with the task.

III. METHOD

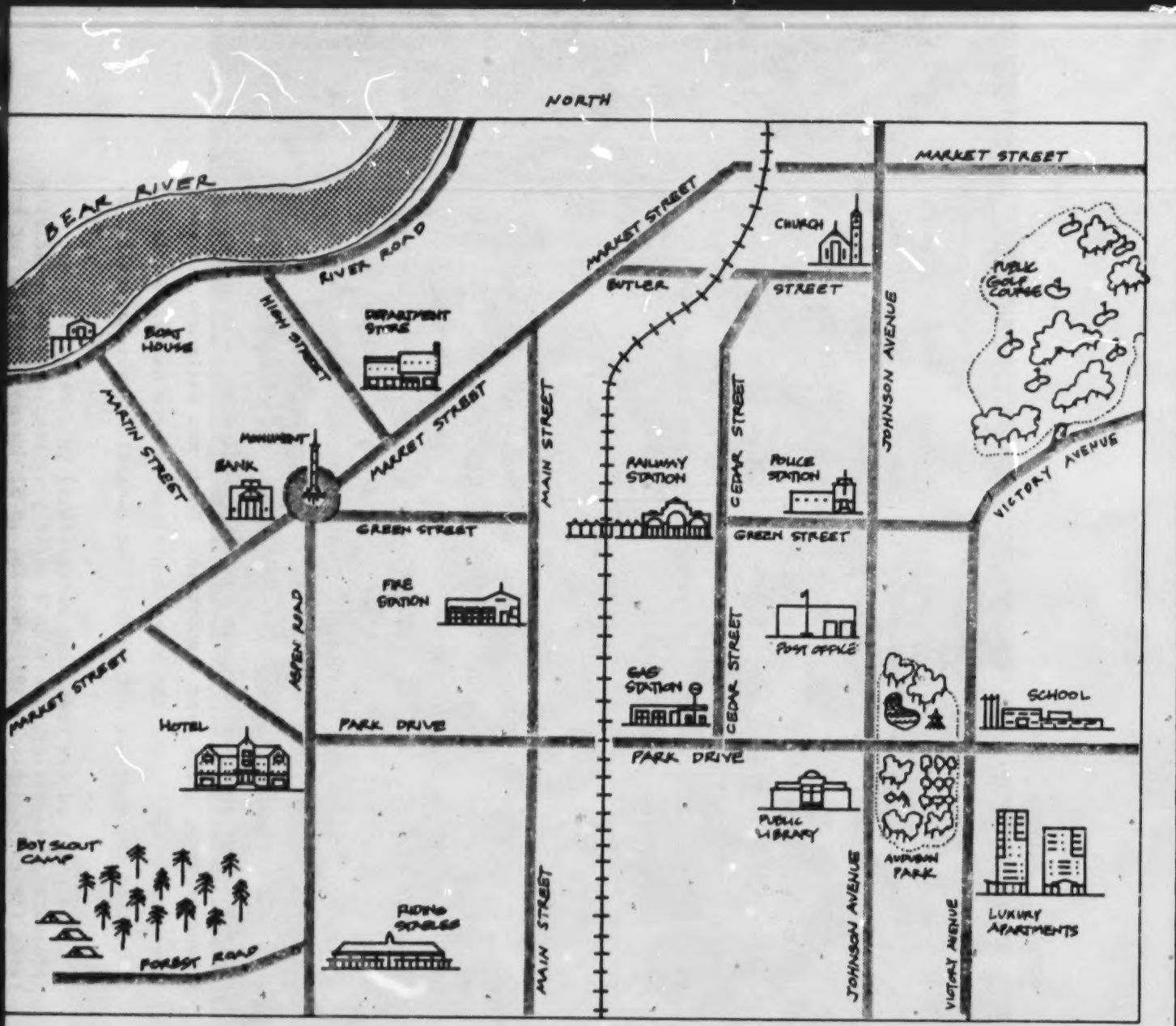
PROTOCOL ANALYSIS

Because our attention focuses on processes that underlie map learning and on differences among individuals' use of these processes, we require detailed knowledge of subjects' behavior while studying a map. Such knowledge must include the information the subjects are attending to and the knowledge and processes being invoked to operate on it. To obtain this detailed information, we collected verbal protocols from subjects during a series of study-recall trials to isolate their various learning behaviors. Subjects' descriptions of their attentional focus, their study strategies, and their evaluations of their learning progress provided insights into the control processes and learning strategies they employ while working on a problem.*

MATERIALS

We constructed two maps of fictitious regions, a town and a country, for use as learning materials in our experiment. The town map, shown in Fig. 1, portrayed a river, streets, buildings, parks, and other typical landmarks. All of these conceptual elements had names associated with them. Streets were drawn in a regular horizontal and vertical grid pattern but included some deviations from that pattern. The countries map, shown in Fig. 2, differed in both scale and content. This map portrayed countries, cities, roads, railroads, and prominent terrain features, including an ocean, an island, rivers, lakes, and a mountain. Roads and railroads did not have verbal labels, but the other map elements were named. While the content of the maps was not selected or controlled systematically, an

*This method has been used successfully to develop and test information processing models in a variety of complex problem-solving tasks (Newell and Simon, 1972; Brooks, 1975; Greeno, 1976; Miller and Goldstein, 1976; Bhaskar and Simon, 1977; Hayes-Roth and Hayes-Roth, 1978).


NORTH
BEAR RIVER
RIVER ROAD
LIGHT HOUSE
HIGH STREET
DEPARTMENT STORE
MARTIN STREET
MONUMENT
BANK
MARKET STREET
MARKET STREET
MAIN STREET
CHURCH
BUTLER
STREET
MARKET STREET
PUBLIC GOLF COURSE
JOHNSON AVENUE
VICTORY AVENUE
RAILWAY STATION
POLICE STATION
CEDAR STREET
GREEN STREET
GREEN STREET
FIRE STATION
ASPEN ROAD
POST OFFICE
CEDAR STREET
GAS STATION
SCHOOL
MARKET STREET
HOTEL
PARK DRIVE
PARK DRIVE
PUBLIC LIBRARY
BOY SCOUT CAMP
AUDUBON PARK
LUXURY APARTMENTS
RIDING STABLES
MAIN STREET
JOHNSON AVENUE
VICTORY AVENUE
FOREST ROAD

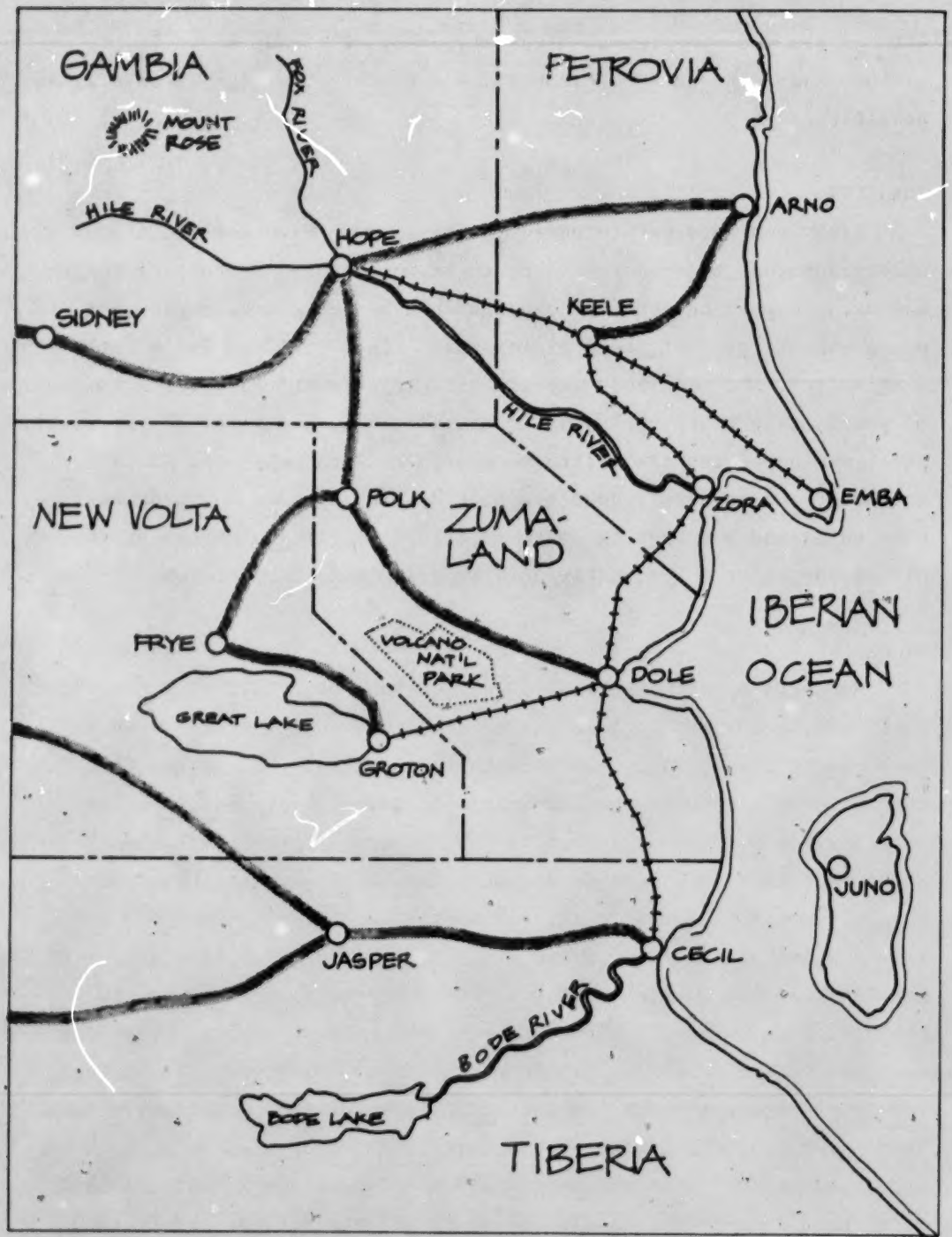


Fig. 2—Countries map

attempt was made to present a variety of types of map elements, to include named and unnamed elements, and to make the maps as natural as possible.

SUBJECTS

Eight subjects participated in the study. Five were UCLA undergraduates, and the remaining three were chosen because of their map-using expertise. These "experts" had had extensive experience using maps as part of their professions. They included DW, a retired Army officer who had field map-using experience and had, for a number of years, taught map reckoning to recruits; FK, a retired Air Force pilot who had extensive military experience with maps; and NN, a scientist who regularly used graphics display systems for geographic data bases and had been an amateur cartographer for a number of years. All of the experts frequently used maps in their current jobs.

PROCEDURE

Subjects were tested individually. They were told that they would be shown a map in a series of six study-recall trials. Their task was to learn, using any techniques they knew, the information in the map well enough to draw the map and answer questions about its contents. During study trials they were required to "think aloud" about what they were looking at, what they were thinking about, and what their strategies were for focusing their attention on and learning the information in the map. A practice trial on a different map familiarized each subject with the study-recall procedure and protocol procedure. Each subject was then presented with either the town map or the countries map to study for two minutes. During that time the subject's verbal protocol was tape-recorded. The subject was then given a pencil and paper and instructed to draw as much of the map as he or she could remember. Unlimited drawing time was allowed. After six study-recall trials (or fewer, if the subject had learned the map perfectly), the subject solved six simple route finding and spatial judgment problems. These problems required recall and

integration of route and location information from the map. For example, one such problem required subjects who had studied the town map to specify the route they would take and the buildings they would pass in traveling from the Luxury Apartments to the gas station and then on to the bank. Answers to these problems were tape-recorded. The study-recall procedure was then repeated for the second map. Order of map presentation was counterbalanced across subjects.

IV. RESULTS AND DISCUSSION

MAP REPRODUCTION

To score subjects' map learning performance, we defined units of information called "elements." An element is a map symbol representing a physical or conceptual entity, such as a building, road, country, lake, or park. Each element could have two attributes: spatial location and a verbal label. The location of a point element was defined relative to the adjacent landmarks (e.g., a building located at the intersection of two streets). The spatial attributes of a one- or two-dimensional element (e.g., a street or country) included its shape and location with respect to adjacent elements. The town map contained 33 elements, all but one of which were named. The countries map contained 43 elements, 26 of which had names and 17 of which were unlabeled.

Recall of spatial and verbal information was scored separately. A labeled element could be reproduced on a subject's map and scored for either correct spatial placement, correct labeling, or both. Unlabeled elements were scored only for correct spatial placement.

The following decision rules were adopted for scoring: (1) Verbal labels of elements had to be completely specified, with the exception of "Street," "Drive," or "Avenue" designations; (2) spatial placements had to preserve the correct interrelationships among the immediately adjacent elements (e.g., on the countries map, Volcano National Park had to be located south of the Polk-Dole Highway and north of the Groton-Dole railroad); (3) major shape characteristics were required for correct spatial placement (e.g., the coastline on the countries map included three bays and a peninsula), but minor shape details were not required (e.g., road and railroad segments on the countries map could be drawn as straight lines).

For each subject, the percentage of verbal information, spatial information, and entire elements correctly recalled at each trial was calculated separately for each map. Recall increased over trials for

every subject. Performance on the final recall trial indicated the variation among subjects on the learning task. Table 1 shows the percentage of map elements recalled correctly and the percentage of verbal and spatial attributes of elements recalled correctly on each subject's last trial on each map.

Performance ranged from 100 percent of the information correct on one subject's reproduced map after five trials (Subject DW) to 18 percent correct after six trials (Subject NN). Subjects' performance was consistent across the two maps and was significantly correlated, $\rho = .78$, $p < .05$. Subjects typically acquired more of the verbal information (88 percent) than the spatial information (77 percent) from the maps. A single exception was Subject FK, who recalled more spatial than verbal information on the countries map. Recall from the countries map was used to compare learning of labeled and unlabeled elements. Across all learning trials, subjects recalled spatial

Table 1

PERCENT OF MAP INFORMATION RECALLED CORRECTLY ON FINAL TRIAL[a]

Item	Subject							
	DW	JM	BW	MS	BB	FK	CD	NN
Countries Map								
Complete map elements	100	95	91	72	53	79	37	19
Verbal information	100	100	100	100	65	77	73	50
Spatial information	100	95	91	72	58	93	46	28
Town Map								
Complete map elements	94	94	97	82	79	48	76	39
Verbal information	100	100	100	100	100	81	97	75
Spatial information	94	94	97	82	79	64	79	45

[a]Trial 5 for Subject DW on the countries map; Trial 4 for DW on the town map; Trial 6 for all other subjects.

information associated with labeled elements better than spatial information associated with unlabeled elements (55 percent versus 42 percent), $t(7) = 2.77$, $p < .02$. While this finding is provocative, we draw no strong conclusions regarding the utility of labels for learning spatial information, since the spatial properties of the labeled and unlabeled elements were not controlled.

PROBLEM SOLVING

The use of map reproductions drawn by the subjects to measure learning has two potential problems. First, subjects might have been able to draw the map on the immediate test using information in a visual short-term memory rather than retrieving information from long-term memory. If this were the case, subjects might be able to draw the map on an immediate test but might not be able to perform more complex problem solving requiring simultaneous retrieval and integration of multiple map elements. Second, some subjects might lack the skills necessary to draw a map even though they had learned the information well.

For these reasons, performance on the six problems following the learning phase for each map were used to test the reliability of the learning data. While problem solving requires processes in addition to simple retrieval of knowledge, performance should correlate with the learning data if those data are reliable. As expected, subjects' problem solving performance was highly correlated with last-trial recall, $r = .90$, $p < .001$.

VERBAL PROTOCOLS

For each study trial, each subject's protocol was analyzed to determine the set and sequence of strategies employed to learn the map. The strategy statements were sorted into categories that seemed to represent the set of high-level processes used during learning. These categories had been identified and operationalized in an analysis of learning protocols from eight pilot subjects.

Figure 3 presents a protocol taken from one subject, CD, on the first trial on the town map. This protocol illustrates several of the strategies we observed repeatedly in subjects' study behavior. Sections of the protocol are numbered for later reference.

In sections 1 and 2 of the protocol, CD notices large, salient features of the map. In section 3, CD switches from a strategy of attending to various salient features scattered around the map to a strategy of consciously controlling what will be attended to. In particular, CD decides to focus on and learn the streets on the map, ignoring the other information. In section 8, this decision is further refined so that only the parallel north-south streets are considered. With this constraint, CD samples individual streets and attempts to learn their names and spatial location using other strategies. In section 5, CD uses the first letter of two intersecting streets, Main and Market, as a mnemonic to remember their names. In section 7, CD details the shape of an irregular street, Victory, and notices an implicit spatial relationship (parallelism) between this street and Johnson Avenue. Finally, in sections 9 and 10, CD produces associative elaborations, using other world knowledge, to relate two street names to adjacent objects on the map.

In our analysis of the subjects' learning protocols, we identified four general types of processes subjects employed during the study trials: attention, encoding, evaluation, and control. Evidence for the first three types was obtained directly from statements in the protocols. Evidence for control processes was inferred from subjects' behavior but was not observed directly in the protocols. Each of these types of high-level process comprises several individual component processes. Table 2 summarizes the four categories of processes and the subprocesses within each.

The first category, attentional processes, includes the processes required for perception of the physical map. Posner and Boies (1971) distinguished three components of attention: general arousal, restriction of attention to task-relevant cues, and switching of attention between tasks. This distinction is useful in understanding

1. Um. First I notice that there's a railroad that goes up through the middle of the map.

2. And then, the next thing I notice is there's a river on the top left corner, and let's see ...

3. There's a main street and ... I guess I'd try and get the main streets first.

4. That would be Market and Johnson and Main. Try to get the relationship of those.

5. On these two streets, they both start with an M.

6. Then I'd just try to get down the other main streets, that ... uh,

7. Victory Avenue comes below the golf course, and then goes straight down and becomes parallel with Johnson, and ...

8. I guess I'd try to learn the streets that are parallel first, parallel to each other. Just try to remember which, in which order they come.

9. I guess with this one I could, since there's a sort of like a forest, I could remember that this is Aspen, and ... um,

10. Let's see, and Victory, I guess I could relate it to the golf [course], winning the golf.

Fig. 3—Verbal protocol from a study trial on the town map

Table 2

PROCESSES IN LEARNING AND CORRESPONDING STRATEGIES FROM THE PROTOCOLS

Process and Subprocesses	Strategy
Attentional	
General arousal	---
Focus of attention	Partitioning
Attention switching	Sampling
	Random
	Stochastic
	Systematic
	Memory-directed
Encoding	
Maintenance	Rehearsal
Elaboration	Verbal learning
	Association
	Mnemonics
	Counting
	Spatial learning
	Imagery
	Labeling
	Pattern encoding
	Relational
	Schema application
Evaluation	
Retrieval	Evaluation
Comparison	---
Control	
Strategy selection	---
Strategy switching	---

the attentional demands on subjects who are perceptually sampling information from a map. In our paradigm, subjects have only one task (to study the map), but they have a variety of perceptual features to which they might attend. General arousal is presumably a background process that determines whether or not and how vigilantly the subject fixates on the map. Focus of attention refers to the process by which subjects restrict eye fixations to a particular subset of the information on the map. Attention switching refers to the process by which subjects shift their focus of attention to a new location on the map.

The encoding process refers to the collection of processes required to hold information from the map in working memory, encode it in long-term memory, and integrate it with other learned information. It is generally assumed that these are conscious processes under subject control (Atkinson and Shiffrin, 1968; Posner and Warren, 1972; Norman and Bobrow, 1977). The encoding of information is facilitated by a variety of well-known elaboration processes, including rehearsal, generation of mnemonic cues, associative elaboration, and the use of imagery.

Evaluation processes provide feedback to the learner about how much he or she is learning, how successful the strategies are, and what information is yet to be learned. Evaluation of learning progress requires the retrieval of knowledge representations from memory, the comparison of the representations against the information encoded on the map, and a decision about whether the two are equivalent.

Finally, we assume there are a set of control processes that direct the overall flow of processing in the learner. In particular, the control processes must include at least a mechanism for selecting from a set of available processes those to be activated (strategy selection) and a mechanism for deciding when to terminate a strategy and switch to a new one (strategy switching).

This list of processes is not intended to be comprehensive or complete. Obviously, many of the basic operations of the human processor, such as perceptual processing and memory search, have been omitted here, although they are presumably invoked by the higher-level processes we have listed. Some of the processes shown in Table 2 cannot be measured with our methodology (e.g., maintenance of general arousal, retrieval and comparison of information from long-term memory) but would have to be studied in carefully controlled processing environments. However, we were able to observe and catalog many of the active strategies that our subjects used to select, filter, and encode information. The strategies that correspond to the presumed learning subprocesses are presented in the second column of Table 2.

Two types of attentional strategies were observed. The first of these, partitioning, was used to focus attention on a subset of the map information. Since a map contained too much information to be assimilated on any one trial, partitioning on early learning trials enabled a learner to attend selectively to only a well-defined aspect of the map. Two specific partitioning strategies were observed: Subjects partitioned the map (1) by spatial region (e.g., by attending only to elements in the northwest corner) or (2) by conceptual category (e.g., by attending only to streets). Sections 3 and 8 of the protocol in Fig. 3 illustrate the second partitioning strategy.

The second type of attentional strategy comprised sampling strategies. Sampling strategies determined shifts in a subject's focus of attention among various map elements and the order in which these elements were processed. Four types of sampling strategies were observed: systematic, stochastic, random, and memory-directed. Systematic sampling involved focusing attention according to a subject-defined decision rule or criterion (e.g., studying elements from west to east or from the outside of the map toward the center). Stochastic sampling involved moving the focus of attention from the current element to an adjacent element, but in no systematic or consistent direction--the sequence of foci seemed to describe a "random walk" (Feller, 1966) through the map. In random sampling, the focus of attention moved haphazardly around the map, with each new focus seemingly independent of the previous focus in both location and content. These three sampling strategies could be invoked on any learning trial. The fourth strategy, memory-directed sampling, could occur on any trial after the first. Memory-directed sampling occurred when a subject decided to study particular elements that had not yet been learned. For example, at the beginning of a new study trial, a subject might decide to study the location of a river because he or she could not not remember it on the previous recall trial.

When information was in a subject's focus of attention, various strategies could be used to elaborate and encode that information in

memory. These strategies may be categorized according to the type of information encoded. Verbal learning strategies operated primarily on semantic and linguistic information, such as the names of buildings or roads. Spatial learning strategies operated primarily on information about shapes and relative locations of objects. Both types of information could be maintained in working memory by actively rehearsing a set of names or location descriptions.

Three verbal learning strategies were observed: counting, mnemonics, and association. Counting helped subjects to cluster several elements sharing a particular property (e.g., "there are five cities on the Iberian coast"). Mnemonics were used to generate easily memorable retrieval cues for a set of names, such as SHA for the northernmost cities on the countries map, Sidney, Hope, and Arno. In Fig. 3, CD uses the letter M as a mnemonic for retrieval of the names of two main streets, Main and Market. The association strategy involved the elaboration of the map information by association to or embellishment with some related prior knowledge. For example, several subjects noted that Market Street on the town map was similar to Market Street in San Francisco in that it formed an oblique angle with intersecting streets. Other associations related two or more elements from the map itself, using world knowledge. In Fig. 3, CD associated Aspen Road with the neighboring forest, and Victory Avenue with the adjacent golf course, thinking of "victory at golf." Strategies of this type were numerous and varied.

Similarly, four strategies for learning spatial information were observed: visual imagery, labeling, pattern encoding, and a relational strategy. Visual imagery was a general learning technique for some subjects. During study trials, these subjects closed their eyes and attempted to draw shapes or name elements in a mental image, attempted to form a mental picture of the map, and focused their attention exclusively on line shapes. Labeling, on the other hand, involves the generation of a verbal cue for recall of a complex spatial configuration. For example, to some subjects, the northern five roads on the countries map might form a figure of a

stick man running to the west, or the coastline might form the profile of a face. In pattern encoding, the subject notices a particular shape or spatial pattern of an element, such as a street that curves to the east. Finally, the relational strategy refers to the verbalization of a spatial relationship between two or more elements. For example, in Fig. 3, CD states that Victory Avenue is "below the golf course" and is "parallel to Johnson."

While we have classified these learning strategies as verbal and spatial, the dichotomy is not strict. Verbal learning strategies could be used to encode some spatial information and vice versa. For example, rehearsal of a list of building names along a particular street might help to encode the implicit spatial ordering of the buildings on the street. Similarly, a visual image of the map might include some names that were printed on the map. However, these effects were only incidental in our study, and subjects used other strategies to learn building locations and object names explicitly.

One encoding strategy, schema application, was used by some subjects to learn either spatial or verbal information. This strategy involves the attempt to learn some information by association with a preexisting, prototypical configuration of such information. For example, a subject might learn the spatial configuration of streets on the town map by initially supposing a prototypical rectilinear grid and then learning how this specific map deviated from that grid.

The third type of process evident in the protocols was evaluation. Subjects monitored their learning progress by considering what they had already learned and what they still needed to study. They would evaluate an element in the current focus of attention to determine whether or not they had learned it well enough to recall it later. This evaluation required a search and retrieval of information from memory and a comparison of that information to the representation of the target element on the map. If subjects decided they had not learned the information, they might decide to use one of the elaboration strategies to study the element.

ANALYSIS OF INDIVIDUAL DIFFERENCES

Intercorrelations between subjects' strategy profiles and learning performance were computed to ascertain the characteristics of good learners' study behavior. While subjects' performance across the two maps was highly reliable, the patterns of strategy usage across the two maps were more variable. The number of occurrences of a strategy on one map was significantly correlated across subjects with the number of occurrences of the same strategy on the other map for only 5 of the 15 strategies. On initial inspection, it appeared that differences in strategy profiles between maps were as pronounced as differences in the subjects' profiles. Therefore, in computing correlations between performance and strategy usage, each subject-map pairing was considered to be an observation. Thus, 16 pairs of observations (each of eight subjects learning each of two maps) entered into the computation of each correlation. Since the performance of subjects was correlated for the two maps, correlations between strategies and performance (as well as regressions to be reported later) were computed using a weighted least-squares procedure (Draper and Smith, 1968). We used this procedure to test the hypothesis that the variance in the performance scores derived from both subject and error components. Likelihood ratio tests indicated that assuming the subject variance parameter to be zero provided as good a fit to the data as assuming any non-zero value. Furthermore, correlations computed using non-zero estimates of subject variance did not differ substantially from those produced assuming no subject-variance component. Therefore, the treatment of subject-map pairs as independent appears to be justified.

The resulting correlation matrix is shown in Table 3. With the exception of a few low correlations that have been included for the purpose of further discussion, only significant correlations ($r > .42$, $p < .05$, $df=14$, one-tailed test) are shown.

Three measures of learning were used: mean correct recall of map elements (spatial and verbal components) per trial (Variable 1), mean number of spatial attributes correctly recalled per trial (Variable 2),

Table 3

INTERCORRELATIONS OF LEARNING PERFORMANCE AND STRATEGIES

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1.	Total recall	--																				
2.	Spatial attributes	.94	--																			
3.	Verbal attributes	.87	.71	--																		
4.	No. of statements	.55	.43	.53	--																	
5.	Partitioning	.31				--																
6.	Random sampling		-.42				--															
7.	Stochastic sampling							--														
8.	Systematic sampling	.58	.50	.44	.45	.46			--													
9.	Memory-directed sampling	.46	.45	.49			-.46			--												
10.	Schema application	-.61	-.56	-.57		-.46					--											
11.	Rehearsal	.54		.51	.95			.44				--										
12.	Association					-.59		.49			.45		--									
13.	Mnemonics													--								
14.	Counting				.53		-.51								--							
15.	Imagery	.66	.56	.54	.81				.58			.86	-.49			--						
16.	Spatial labeling																--					
17.	Pattern encoding	.50	.44	.52					.47	.63							.55	--				
18.	Relational	.57	.43	.56	.84		-.49	.51	.52			.69			.49	.56	.51	.61	--			
19.	Evaluation	.19								.62								.45		--		
20.	Evaluation: unlearned	.61	.46	.68												.49					--	
21.	Evaluation: accuracy	.55	.46	.48																	.82	--

and mean number of verbal attributes correctly recalled per trial (Variable 3). Variable 4 is the mean number of strategy statements of any type uttered per trial. This number varied from 4.3 to 47.7. Variables 5 through 19 are the strategies discussed above. All of these variables were measured as the number of occurrences of the strategy in a subject's entire learning protocol. Variables 5 through 8, 10, and 15 corresponded to strategies that, with few exceptions, were used at most once per trial. Thus, the values of these variables ranged from 0 to 6. The frequencies of the other strategies ranged from 0 to 48 and were irregularly distributed. Variable 20 is the percentage of the evaluation statements (Variable 19) that were negative; that is, the percentage of the time that subjects decided they did not know the element that they evaluated. Variable 21 is the percentage of all evaluation statements that were, in fact, accurate. That is, when subjects assessed whether or not they knew an element, they could be either correct or incorrect in the evaluation. Accuracy was assessed by comparing the subjects' statements about the elements with the accuracy of the reproductions on the previous trial.

Overall loquacity was not related to performance. There was no correlation between the mean number of words in subjects' protocols and recall. But the number of strategy statements in the protocols was correlated with performance: Good learners made more strategy statements. However, 90 percent of the variance in the number of strategy statements was due to a single strategy, rehearsal. When rehearsal is discounted, there are no differences across subjects in the number of strategy statements. Furthermore, there was no difference between good and poor learners in the number of <u>different</u> strategies used. Thus all subjects were roughly equivalent in the extent of their verbal production, in the frequency of strategy usage, and in the variety of strategies employed during learning.

All learners used rich and varied verbal learning strategies, among which only rehearsal was correlated with performance. On the other hand, several spatial learning strategies were significantly correlated with performance: imagery, pattern encoding, and

relational strategies. In addition, the two most advantageous sampling strategies, systematic sampling and memory-directed sampling, were correlated with learning. The use of the schema application strategy was inversely related to performance--that is, schema application was used by only poor learners and was not successful. All subjects used the evaluation strategy ($r = .19$), but both the accuracy of the evaluations and the proportion of evaluations that were performed on unlearned elements were correlated with recall.

A stepwise multiple regression was carried out to partial out the effects due to intercorrelations among the variables. The stepwise procedure was used because the subset of strategies that would be predictive of performance could not be identified a priori. (The obtained results did not differ when a simple regression procedure was used.) Table 4 shows the order in which variables entered the regression analysis and their contributions to subject variance. Five variables were found to contribute significantly: imagery, memory-directed sampling, schema application, evaluation accuracy, and relational strategy. These variables, then, constitute the set of independent predictors of subject performance on the learning task.

Table 4

VARIABLES INTRODUCED IN STEPWISE REGRESSION ANALYSIS OF MAP RECALL

Variable	R[a]	R^2 Increment[b]
1. Imagery	.66	.440
2. Memory-directed sampling	.85	.281
3. Schema application	.89	.071
4. Evaluation accuracy	.93	.065
5. Evaluation	.94	.028
6. Spatial labeling	.95	.018
7. Relational	.98	.061
8. Random sampling	.99	.012
9. Mnemonic	.99	.006

[a]Multiple correlation coefficient.

[b]Proportion of variance accounted for by each variable.

Of the remaining variables that were significantly correlated with learning, systematic sampling, rehearsal, and evaluation of unlearned elements were all correlated with imagery and thus did not have significant regression weights. These intercorrelations, if not spurious, might have been obtained for one of two reasons: Good subjects might have used one or more macro-strategies, that is, strategies incorporating several of the observed study strategies. Or the strategies might have been independent, but good learners might have known and used all of them.

In order to examine the relationships among these strategies and the dynamics of learning, we contrasted learning protocols of good learners with those of poor learners. Good learners were defined as subjects who recalled at least 90 percent of the elements correctly by the final trial. This criterion distinguished six good protocols (three subjects on each of two maps) from ten poor protocols (five subjects on each map). Mean final trial performance scores were 95 percent for the good learners and 58 percent for the poor learners. Using this criterion, several reliable differences between good and poor learners in the use of study strategies were identified. The major strategy differences in each processing category are summarized below. Mann-Whitney U-tests, with sample sizes of six and ten and an alpha level of .05, were used to evaluate the reliability of reported differences.

Attention. When good learners used a partitioning strategy, they also employed either a systematic or stochastic sampling strategy (83 percent of the protocols). When good learners decided to focus on a subset of the map information, they would sample only elements in the partitioned set. These strategies were used primarily on early learning trials, when the majority of the map information had not been learned, and in conjunction with image formation of the spatial attributes of the map. In contrast, poor learners either (1) did not use the partitioning strategy (30 percent of the protocols), (2) failed to adopt a consistent sampling strategy (i.e., used random sampling) to accompany partitioning (40 percent), (3) were unable to

restrict their attention to elements in the partitioned set (20 percent), or (4) abandoned the partitioning strategy abruptly and prematurely (20 percent). This last action occurred when subjects could not find a strategy for learning the sampled information.

On later trials, when the basic framework of the map had been learned, good learners relied heavily on memory-directed sampling to determine their focus of attention. That is, good learners knew which details were as yet unlearned and searched for and focused on them. Their strategies for selecting attentional focus were thus goal-directed: Find unlearned map elements and focus attention on them. Poor learners, on the other hand, might use this sampling strategy at the beginning of a study trial to find one or two unlearned details, but they would then abandon the strategy in favor of a stochastic or random strategy.

The ability to focus successively on only unlearned information, demonstrated by good learners, would seem to depend on sophisticated perceptual and attentional guidance processes, such as those suggested by Neisser (1976) and Parker (1978). Neisser and Parker assumed that when a person focuses attention on a particular element, additional information is extracted from the periphery of the visual field. This information is evaluated in memory, and the results are used to guide additional fixations. Our subjects, when viewing a map, undoubtedly processed more perceptual information than they reported. However, we assume that for an element to be reported as being the current focus of attention, and for the element to be subjected to conscious encoding processes, it must be contained in the current fixation.

Encoding. Effective learners used frequent and varied spatial learning strategies, while poor learners did not. All good learners reported constructing in memory and rehearsing a visual image of the map. The use of imagery as a learning strategy thus frequently entailed rehearsing a set of recently perceived elements. This accounts for the high correlation ($r = .86$) between imagery and rehearsal. Other simple strategies that good learners used to elaborate and refine their knowledge of spatial location included

noticing and encoding explicit shapes (pattern encoding) or spatial relations (relational) among two or more map elements. These strategies were used significantly more often by good learners than by poor learners. Poor learners frequently reported that they could not think of a strategy for learning the information in their focus of attention. In general, their strategy repertoire was more limited than that of good learners. In addition, poor learners sometimes attempted to use strategies that were ill-suited to the task and were unsuccessful (e.g., the use of a schema for learning the overall spatial layout of the map).

Evaluation. All learners evaluated their learning progress extensively after each recall trial. However, three characteristics of the evaluation process distinguished good learners from poor learners: First, good learners evaluated primarily unlearned elements (82 percent of all evaluation statements), ignoring evaluative considerations of information they had already learned. Poor learners evaluated a significantly smaller proportion (62 percent) of unlearned elements and instead spent some of their study time confirming that they knew certain information. This is surprising in light of the fact that poor learners, by definition, knew less of the information than good learners, and hence their a priori probability of picking an unlearned element to evaluate was higher than that of the good learners. However, as noted above, good learners appeared to be goal-directed in studying the map. At each new learning trial, they would know what information they had not yet learned, find that information on the map, and then study it, using an appropriate elaboration strategy. Poor learners seemed more data-driven. They would first focus on a randomly selected map element and then evaluate the element in memory to decide whether or not it had been learned.

Second, good learners were significantly more accurate in their evaluations (96 percent correct) than poor learners (82 percent). That is, good learners were superior at determining their current state of learning and "knowing what they know." Such knowledge about the state of memory has been referred to as metamemory, and its

development has been extensively studied in children (Brown, 1975, 1978; Flavell and Wellman, 1977). Although this phenomenon has been studied very little in adults, it may represent an important source of systematic individual differences in learning and memory tasks.

Finally, good and poor learners differed in their behavior following an evaluation. When a good learner decided that an element had not yet been learned, he or she immediately studied the element. The conditional probability of a good learner immediately studying an element, given that he or she had made a negative or "unlearned" decision about it, was .95. For poor learners, this conditional probability was significantly lower (.75). After making a negative evaluation, the poor learners would frequently shift their focus of attention to a new element without studying the unlearned information.

PERFORMANCE OF EXPERTS

Because three subjects were highly experienced at viewing and using maps, it was expected that they would also be the best learners. However, the experts' performance was not uniform: One of them, DW, was the best learner, with a mean across maps of 97 percent correct on the last trial. Expert FK ranked sixth out of eight subjects, with a mean last-trial performance of 63.5 percent. And NN, the third expert, was the worst learner, having a mean last-trial performance of 28.5 percent. These experts were chosen because of their extensive experience in reading, using, and learning maps. The vast differences among them in performance on the learning task suggest that the observed subject differences cannot be explained by differential familiarities with the type of material or task domain. If familiarity with maps were the critical variable, then all experts should have performed well.

Instead, differences among experts seemed to be due to differences in the study strategies that they used. These strategy choices matched their self-reported aptitudes for learning. For example, the best learner, DW, stated that he had good visual memory and frequently constructed visual images to learn and remember

information. In learning the experimental maps, he made extensive use of visual imagery and other spatial learning strategies. Because he was able to use these strategies effectively for learning, he had no difficulty with the hypothetical geography of the maps. That is, he was quite successful at learning the spatial information on the map "as is," without relying on memory of other maps of the same type to aid learning. On the other hand, NN, the worst learner, reported that he had very poor memory for spatial information and had never experienced having mental images. In learning the map, NN used primarily verbal learning strategies. Rather than using imaginal strategies to learn object locations and relationships, NN attempted to learn them by relying on his prior knowledge of common geographical configurations (e.g., noticing that a park was across the street from a school). Because the geographic information on the maps was fictitious (although not anomalous), this technique was unreliable for learning much of the spatial information. Subject NN reported that he found the learning task to be extremely difficult and did not attempt to learn some of the more complex spatial configurations of information on the map, such as the shape of the coastline and railroads on the countries map.

The third map expert, FK, was variable in his learning performance. On both maps, FK had difficulty learning verbal information, such as the names of the cities, streets, and countries. He ranked fifth among eight subjects on last-trial recall of verbal information from the countries map, and seventh on the town map. On the other hand, FK had little difficulty learning most of the spatial information. On the countries map, where much of the spatial information was unlabeled, FK learned that information as well as the best learners. On the town map, he learned the locations of the buildings and landmarks rapidly but avoided learning the detailed shapes and locations of the streets because he had difficulty with their names. This superiority of spatial learning performance over verbal learning performance was the reverse of the trend for the other subjects, who found the verbal information easiest to learn. This

deviance from the norm may perhaps be explained by FK's professional experience with maps. As an Air Force pilot, he was accustomed to learning spatial information for later location and identification from the air. To a pilot performing target acquisition and reconnaissance, learning the spatial locations and interrelationships of terrain features is more important than learning the names. As FK explained, "When you're flying, you don't really care if that mountain is Mont Blanc or Mount something-or-other, as long as it's where it's supposed to be in relation to everything else." Since learning names was unimportant in FK's past map learning experience, he did not have (and could not think of) any useful strategies for remembering them.

V. CONCLUSIONS

It is evident from these analyses that successful map learning depends on particular study strategies that are useful for this task. As noted earlier, an important characteristic of the map learning task is that all the information to be learned is presented simultaneously. As a result, rate and content of information availability depend on the decisions and actions of the learner. The lack of structure in the learning procedure increases the importance of employing appropriate strategies for learning. In fact, the influence of strategies on determining learning rate outweighs the potential effects of prior experience with using or learning maps.

We observed several differences in strategy usage between good and poor learners. Good learners coped with the task's lack of structure by formulating a learning plan. They structured the learning task by deciding how to segment and focus systematically on subsets of information from the map. They demonstrated a variety of successful strategies for learning both spatial relationships and verbal labels. Finally, they evaluated their learning progress consistently and accurately, using their knowledge about their own uncertainties to determine their visual fixations and study behaviors. Poor learners' strategy behavior deviated in a number of ways from that of the successful learners. These deviations might be regarded as "bugs" in their learning procedures that retarded rapid learning. From our analysis, we have identified 10 learning bugs. Each poor learner exhibited some of them but no learner exhibited all of them. The bugs are summarized briefly below. They are grouped according to type of process: 1 is a bug in attentional processes, 2 through 5 are bugs in encoding processes, 6 through 8 are bugs in evaluation processes, and 9 and 10 are bugs in control processes.

1. No attention-focusing plan. The subjects made no decision about how to partition and sample information from the map, so they

were either overwhelmed by the amount of map information or they studied the information haphazardly.

2. Ineffective strategies. The strategies employed to acquire information did not produce learning.

3. Inappropriate strategies. The strategies that were used to learn information were inappropriate for the given materials.

4. Unavailability of strategies. The subject could not think of strategies for learning certain information on the map. Typically, this meant the subject was unable to use imaginal strategies on complex spatial information. For example, he or she would decide to learn all the street locations but could think of no procedure for doing so.

5. Knowledge integration failure. The subject could not integrate spatially two types of knowledge acquired during study of different subsets of the map. For example, road shapes may have been learned separately from city locations, and the subject would fail to integrate the information, resulting in errors in placement of roads with respect to cities.

6. Infrequent evaluations. The subject did not monitor his or her learning progress frequently to determine future study behaviors.

7. Reevaluation of learned information. The subject frequently evaluated information that he or she had already learned.

8. Inaccurate evaluations. The subject inaccurately decided whether or not he or she had already learned an element.

9. Premature abandonment of attentional plan. The subject abandoned a plan for structuring and sampling the map information prior to its completion and then began sampling study items randomly.

10. Failure to use evaluation feedback. After deciding that an element had not been learned, the subject would shift his or her focus of attention to a new element without studying the unlearned information.

While these data identify important individual differences on this learning task, we can only speculate on the cause of these differences. Hunt (1978) discussed three sources of individual

differences in cognition: knowledge, the mechanics of information processing, and simple processing strategies. The data we obtained from expert map users strongly suggest that for the map learning task, knowledge of the problem cannot predict performance differences. However, the second and third sources of differences are plausible predictors of map learning performance. The elementary mechanics of information processing, including decoding, memory search, and comparison, are all correlated with verbal ability and seem to be stable individual traits (Hunt, 1978). Such processes are important components in knowledge acquisition, regardless of the high-level strategies subjects use during study. We have not carefully investigated these automatic processes, since our analysis focuses primarily on those strategies that were more immediately available to subjects' introspection. However, we did observe substantial individual differences in the accuracy of subjects' memory evaluations, a process that requires the retrieval of knowledge from memory and its comparison with perceptual information in the current focus of attention. This result provides indirect support for the hypothesis that these processes are important in explaining performance differences.

The most significant predictors of performance, however, appear to be the controlled strategies that subjects invoke during learning. Even on simple processing tasks, subjects vary in the type of processes they use (Hunt, 1978) and in their effectiveness in using common strategies (Baron, 1977; Sternberg, 1977). In our study, subjects varied markedly in the strategies they used, and the strategy profile could predict the degree of success on the task.

Therefore, it appears likely that both stable low-level processing abilities and higher-level strategy choices contribute to differences among individuals. However, the relative contribution of these factors remains an empirical question. On the one hand, it might be presumed that poor learners could be trained to use the high-level processing strategies that were observed in good learners and were correlated with performance. In particular, the various

spatial learning strategies and the focusing on and study of unlearned information were salient discriminators of good and poor learners. Because these strategies accounted for much of the variance in learning, we might expect that learners who could be taught to use them could significantly improve their learning performance. On the other hand, if low-level, automatic information processes account for much of the variation in learning performance, or if the use of high-level strategies depends upon these basic abilities, then we might expect a subject's performance to be constant across various training conditions. If this hypothesis were correct, for example, poor learners might not be able to learn to use visual imagery effectively because they have poor visualization ability. Similarly, the evaluation of the current state of memory may be so dependent upon immutable automatic processes that strategy training would prove largely unsuccessful in altering performance. While both hypotheses have received empirical support in various other task domains, this issue remains an open question in the current domain.

BIBLIOGRAPHY

Anderson, J. R., and G. H. Bower, Human Associative Memory, V. H. Winston and Sons, Washington, D.C., 1973.

Atkinson, R., and R. Shiffrin, "Human Memory: A Proposed System and Its Control Processes," in K. Spence and J. Spence (eds.), The Psychology of Learning and Motivation, Vol. 2, Academic Press, New York, 1968.

Baddeley, A. D., S. Grant, E. Wight, and N. Thomson, "Imagery and Visual Working Memory," in P.M.A. Rabbitt and S. Dornic (eds.), Attention and Performance, Vol. V, Academic Press, London, 1975.

Baron, J., "Intelligence and General Strategies," in B. Underwood (ed.), Strategies in Information Processing, Academic Press, New York, 1977.

Beck, R. J., and D. Wood, "Cognitive Transformation from Urban Geographic Fields to Mental Maps," Environment and Behavior, Vol. 8, 1976, pp. 199-238.

Belmont, J., and E. Butterfield, "Learning Strategies as Determinants of Memory Deficiencies," Cognitive Psychology, Vol. 2, 1971, pp. 411-420.

Bhaskar, R., and H. A. Simon, "Problem Solving in Semantically Rich Domains: An Example from Engineering Thermodynamics," Cognitive Science, Vol. 1, 1977, pp. 192-215.

Brooks, L. R., "Spatial and Verbal Components of the Act of Recall," Canadian Journal of Psychology, Vol. 22, 1968, pp. 349-368.

Brooks, R., A Model of Human Cognitive Behavior in Writing Code for Computer Programs, Carnegie Mellon University, Report AFOSR-TR-1084, 1975.

Brown, A., "The Development of Memory: Knowing, Knowing About Knowing, and Knowing How to Know," in H. Reese (ed.), Advances in Child Development and Behavior, Vol. 10, Academic Press, New York, 1975.

Brown, A., "Knowing When, Where, and How to Remember: A Problem of Metacognition," in R. Glaser (ed.), Advances in Instructional Psychology, Lawrence Erlbaum Associates, Hillsdale, New Jersey, 1978.

Cohen, R., and T. Sandberg, "Relation Between Intelligence and Short-Term Memory," Cognitive Psychology, Vol. 9, 1977, pp. 534-554.

Cooper, L. A., "Mental Rotation of Random Two-Dimensional Shapes," Cognitive Psychology, Vol. 7, 1975, pp. 20-43.

Cooper, L. A., "Demonstration of a Mental Analog of an External Rotation," Perception and Psychophysics, Vol. 19, 1976, pp. 296-302.

Cooper, L. A., and P. Podgorny, "Mental Tranformations and Visual Comparison Processes: Effects of Complexity and Similarity," Journal of Experimental Psychology: Human Perception and Performance, Vol. 2, 1976, pp. 503-514.

Cooper, L. A., and R. N. Shepard, "Chronometric Studies of the Rotation of Mental Images," in W. G. Chase (ed.), Visual Information Processing, Academic Press, New York, 1973.

Downs, R., and D. Stea, Image and Environment, Aldine Publishing Co., Chicago, 1973.

Downs, R., and D. Stea, Maps in Minds, Harper & Row, New York, 1977.

Draper, N. R., and H. Smith, Applied Regression Analysis, John Wiley and Sons, Inc., New York, 1968.

Estes, W., "Learning Theory and Intelligence," American Psychologist, Vol. 29, 1974, pp. 740-749.

Feller, W., An Introduction to Probability Theory and Its Applications, Vol. 1., John Wiley and Sons, Inc., New York, 1966.

Flavell, J., and H. Wellman, "Metamemory," in R. Kail and J. Hagen (eds.), Perspectives on the Development of Memory and Cognition, Lawrence Erlbaum Associates, Hillsdale, New Jersey, 1977.

Greeno, J. G., "Indefinite Goals in Well-Structured Problems," Psychological Review, Vol. 6, 1976, pp. 479-491.

Hardwick, D. A., C. W. McIntyre, and H. L. Pick, Jr., "The Content and Manipulation of Cognitive Maps in Children and Adults," Monographs of the Society for Research in Child Development, Vol. 41, 1976.

Hayes-Roth, B., and F. Hayes-Roth, Cognitive Processes in Planning, The Rand Corporation, R-2366-ONR, October 1978.

Hunt, E., "The Mechanics of Verbal Comprehension," Psychological Review, Vol. 85, 1978, pp. 109-130.

Hunt, E., N. Frost, and C. Lunneborg, "Individual Differences in Cognition: A New Approach to Intelligence," in G. Bower (ed.), Advances in Learning and Motivation, Vol. VII, Academic Press, New York, 1973.

Hunt, E., C. Lunneborg, and J. Lewis, "What Does it Mean To Be High Verbal?," Cognitive Psychology, Vol. 7, 1975, pp. 194-227.

Jackson, M., and J. McClelland, "Processing Determinants of Reading Speed," Journal of Experimental Psychology: General, in press.

Jenkins, J. J., J. Wald, and J. B. Pittenger, "Apprehending Pictorial Events: An Instance of Psychological Cohesion," in C. W. Savage (ed.), Minnesota Studies in the Philosophy of Science, Vol. 9, University of Minnesota Press, Minneapolis, 1978.

Johnson, E. S., "Validation of Concept-Learning Strategies," Journal of Experimental Psychology: General, Vol. 3, 1978, pp. 237-266.

Kosslyn, S., "Information Representation in Visual Images," Cognitive Psychology, Vol. 7, 1975, pp. 341-371.

Kosslyn, S. M., "Can Imagery Be Distinguished from Other Forms of Internal Representation? Evidence from Studies of Information Retrieval Time," Memory and Cognition, Vol. 4, 1976, pp. 291-297.

Kosslyn, S. M., and J. R. Pomerantz, "Imagery, Propositions, and the Form of Internal Representations," Cognitive Psychology, Vol. 9, 1977, pp. 52-76.

Kosslyn, S. M., T. M. Ball, and B. J. Reiser, "Visual Images Preserve Metric Spatial Information: Evidence from Studies of Image Scanning," Journal of Experimental Psychology: Human Perception and Performance, Vol. 4, 1978, pp. 47-60.

Lyon, D., "Individual Differences in Immediate Serial Recall: A Matter of Mnemonics?," Cognitive Psychology, Vol. 9, 1977, pp. 403-411.

Lynch, K., The Image of the City, M.I.T. Press, Cambridge, Massachusetts, 1960.

Mayer, R. E., "Information Processing Variables in Learning to Solve Problems," Review of Educational Research, Vol. 45, 1975, pp. 525-541.

Mayer, R. E., and J. G. Greeno, "Structural Differences Between Learning Outcomes Produced by Different Instructional Methods," Journal of Educational Psychology, Vol. 63, 1972, pp. 165-173.

Miller, M., and I. Goldstein, "Parsing Protocols Using Problem Solving Grammars," MIT AI Memo 385, 1976.

Neisser, U., Cognition and Reality, Freeman, San Francisco, 1976.

Newell, A., and H. A. Simon, Human Problem Solving, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1972.

Norman, D., and D. Bobrow, Descriptions: A Basis for Memory Acquisition and Retrieval, Technical Report No. 74, Center for Human Information Processing, University of California, San Diego, 1977.

Parker, R., "Picture Processing During Recognition," Journal of Experimental Psychology: Human Perception and Performance, Vol. 4, 1978, pp. 284-293.

Paivio, A., Imagery and Verbal Processes, Holt, Rinehart and Winston, New York, 1971.

Piaget, J., and B. Inhelder, The Child's Conception of Space, Norton, New York, 1967.

Posner, M., and S. Boies, "Components of Attention," Psychological Review, Vol. 78, 1971, pp. 391-408.

Posner, M. I., and C.R.R. Snyder, "Attention and Cognitive Control," in R. Solso (ed.), Information Processing and Cognition: The Loyola Symposium, Lawrence Erlbaum Associates, Hillsdale, New Jersey, 1975.

Posner, M., and R. Warren, "Traces, Concepts, and Conscious Construction," in A. Melton and E. Martin (eds.), Coding Processes in Human Memory, John Wiley and Sons, Inc., Washington, D.C., 1972.

Rohwer, W. D., Jr., "Elaboration and Learning in Childhood and Adolescence," in H. W. Reese (ed.), Advances in Child Development and Behavior, Vol. 8, Academic Press, New York, 1973.

Shepard, R. N., "Form, Formation, and Transformation of Internal Representations," in R. Solso (ed.), Information Processing and Cognition: The Loyola Symposium, Lawrence Erlbaum Associates, Hillsdale, New Jersey, 1975.

Shepard, R., "The Mental Image," American Psychologist, Vol. 33, 1978, pp. 125-137.

Shepard, R. N., and J. Metzler, "Mental Rotation of Three-Dimensional Objects," Science, Vol. 171, 1971, pp. 701-703.

Shepard, R. N., and P. Podgorny, "Cognitive Processes that Resemble Perceptual Processes," in W. K. Estes (ed.), Handbook of Learning and Cognitive Processes, Lawrence Erlbaum Associates, Hillsdale, New Jersey, 1978.

Shimron, J., On Learning Maps, Technical Report, Center for Human Information Processing, University of California, San Diego, La Jolla, 1975.

Siegel, A. W., K. C. Kirasic, and R. V. Kail, "Stalking the Elusive Cognitive Map: The Development of Children's Representations of Geographic Space," in J. F. Wohlwill and I. Altman (eds.), Human Behavior and Environment: Children and the Environment, Vol. 3, Plenum Press, New York, 1978.

Siegel, A. W., and S. H. White, "The Development of Spatial Representations of Large-Scale Environments," in H. W. Reese (ed.), Advances in Child Development and Behavior, Vol. 10, Academic Press, New York, 1975.

Snow, R., "Eye Fixation and Strategy Analyses of Individual Differences in Cognitive Aptitudes," in A. Lesgold, J. Pellegrino, S. Fokkema, and R. Glaser (eds.), Cognitive Psychology and Instruction, Plenum Press, New York, 1978.

Sternberg, R., Intelligence, Information Processing, and Analogical Reasoning: A Componential Analysis of Intelligence, Lawrence Erlbaum Associates, Hillsdale, New Jersey, 1977.

Voss, J., "Cognition and Instruction: Toward a Cognitive Theory of Learning," in A. Lesgold, J. Pellegrino, S. Fokkema, and R. Glaser (eds.), Cognitive Psychology and Instruction, Plenum Press, New York, 1978.